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Health and endogenous growth

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Abstract

The focus of endogenous growth theory on human capital formation and the physical embodiment of knowledge in people, suggests the integration of the growth supporting character of health production and the growth generating services of human capital accumulation in an endogenous growth framework. We show that a slow down in growth may be explained by a preference for health that is positively influenced by a growing income per head, or by an ageing population. Growth may virtually disappear for countries with high rates of decay of health, low productivity of the health-sector, or high rates of discount. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

These days total health costs in Western economies are roughly 8–9% of GDP, whereas expenditures on education account for another 6–7%.¹ The expenditures on education are generally motivated by the insight that education provides a strong contribution to economic growth. Health expenditures on the other hand, have been a cause of general concern for some time now, especially because of the seemingly autonomous and permanent character of rises in the corresponding costs. This is due to the fact that a significant part of total health costs are associated with care rather than cure. The former costs have shown a tendency

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¹ See OECD (1999) and The Economist Yearbook (1998), respectively.

to rise, largely due to the ageing of the population.² However, one should not forget that health is also a very important factor in economic growth.

The impact of education on economic growth has been recognised for more than a decade now in economic theory. In his pioneering endogenous growth model, Lucas (1988) underlines the principal importance of human capital formation for growth and development in a relatively straightforward manner.³ But, paradoxically, in this and subsequent growth models, it is generally overlooked that human capital formation as a source of growth is quite literally embodied in people.⁴ Nonetheless, people can provide effective human capital services only if they are alive and healthy. Therefore, the general acceptance of human capital formation as a source of growth also warrants a closer look at how changes in the health-state of the population may influence growth and hence total welfare.⁵

As observed by Grossman (1972, p. xiii), health contributes to well-being and economic performance in several ways. From a growth perspective, the positive contribution of a ‘good health’ to labour productivity is particularly important. However, the provision of health requires resources. As a consequence, there seems to be a direct trade-off between health and human capital accumulation: an expansion of the health sector may promote growth through increased health of the population, while a contraction of the health sector could also free the resources necessary to promote growth by means of an increase in human capital accumulation activities.⁶ Moreover, this trade-off is complicated because of the asymmetries in the productivity characteristics of health generation and the accumulation of human capital. Baumol (1967), for instance, takes the health sector as an example of a sector which permits “... only sporadic increases in productivity” because “... there is no substitute for the personal attention of a physician ...”, as opposed to human capital accumulation activities, which give rise to “... technologically progressive activities in which innovations, capital accumulation, and economies of large scale make for a cumulative rise in output per man hour”.⁷

² For instance, according to Polders et al. (1997, p. xii), roughly 50% of the total rise in health costs between 1988 and 1994 in the Netherlands was due to both an ageing population and factors like technical change and demand shifts. And according to Centraal Planbureau (1999, p. 5), more than one-third of total health expenditures in 1997 in the Netherlands was directly associated with care for the elderly and the (mentally) handicapped. This does not include cure expenditures for these groups of patients.

³ See also Romer (1990) and Aghion and Howitt (1992) for examples of human capital formation or knowledge generation as the source of economic growth.

⁴ A notable exception is Ehrlich and Lui (1991), who focus on the way in which subsequent generations and the trade between them influence human capital formation, longevity and growth in an overlapping generations setting.

⁵ In Muysken et al. (1999) we show how this point has been recognized in many empirical growth studies, in particular on economic convergence — see for instance Knowles and Owen (1997) — but not in theoretical growth models.

⁶ This provides an interesting contrast to microeconomic analysis that suggests the existence of complementarity between health and education. Fuchs (1982), for instance, argues that increases in health investment would lengthen one’s life span, *ceteris paribus*, and hence increase the returns on investment in education. An alternative explanation would be that a higher level of education would go hand in hand with increases in the preference for health (possibly due to the rise in the opportunity costs of not being healthy).

⁷ Baumol (1967, pp. 416, 423, 415, respectively). It is these differences in productivity that are the cause of Baumol’s disease.

In terms of the growth model, this implies that we assume that the generation of health services is characterised by decreasing returns, whereas human capital accumulation is generally modelled using increasing returns.⁸ Another asymmetry between health and human capital which should be recognised in the analysis is that health directly affects welfare and therefore should be included in the utility function next to consumption — at least in Western economies. As a consequence, there is also a direct trade-off between resources used in the health sector and the final goods sector.⁹

In order to analyse both trade-offs and their consequences for economic growth, we extend the endogenous growth framework of Lucas (1988).¹⁰ We take into account that health influences intertemporal decision-making in three different ways. First, it serves as the ‘*conditio sine qua non*’ to the provision of human capital services. Second, the provision of health services directly competes with the provision of labour services allocated to the production of output and time spent on human capital accumulation. The third way in which health influences intertemporal decision-making follows from the observation that health can generate positive utility of its own. In addition to this, we take account of the intertemporal welfare effects of providing health services through the positive impact on longevity.

Our model shares some features with Barro (1990), who looks at the contribution of government expenditures to welfare directly and through government expenditures induced productivity growth in an *AK*-setting.¹¹ However, unlike Barro (1990), we focus on the embodiment of human capital in people, and the role of the provision of health services in enabling society to reap both the productive effects and the direct welfare effects of having a healthy population. The ‘labour augmentation framework’ of the Lucas (1988) model therefore provides a ‘natural’ point of departure for our analysis.

In our model, we distinguish between the active part of the population and the inactive part. The latter may increase with longevity because of increased health — but this also expands the demand for health services. We assume that the provision of labour services by the active part of the population depends both on the average level of health of the work force and on the amount of human capital per (health-) worker. The idea is that a deterioration of health reduces the number of effective working days embodied in a person and hence in the population. From that perspective, health and human capital are complements, in that a low health status will lead to a low supply of human capital services, *ceteris paribus*. However, from the perspective of the generation of effective human capital services, the

⁸ Decreasing returns in health services are used in Forster (1989), Ehrlich and Chuma (1990) and Johansson and Lofgren (1995), increasing returns in human capital generation appear in the growth models mentioned above.

⁹ This is reflected for instance in the fact that, in Western economies at least, a significant part of total health costs are associated with care rather than cure — mainly because of the ageing of the population. See also Footnote 2.

¹⁰ Grossman (1972), followed up by, for instance, Muurinen (1982), Forster (1989) and Ehrlich and Chuma (1990) have concentrated on the provision of health services from a micro economic demand perspective. Meltzer (1997), using ‘intertemporal cost effectiveness analysis’ at the micro-level, even goes as far as defining a lifetime utility maximization problem that internalizes all future costs (medical and non-medical) of medical interventions, through changes in survival probabilities. Our analysis integrates both costs (in terms of consumption foregone) and benefits (in terms of productivity and longevity effects) at the macro-level.

¹¹ The *AK*-model is the simplest endogenous growth model that exhibits the key property underlying endogenous growth, namely the absence of diminishing returns to capital. This property is implied by the use of the linear production function $Y = AK$, where Y is output, K capital and A (fixed) capital productivity. See further Barro and Sala-i-Martin (1995) for an extensive discussion of the *AK*-framework.

provision of health services is also a direct substitute for the generation of human capital. We show that our model defines an optimal mix of the provision of health and human capital accumulation that depends on the parameters describing the characteristics of the entire economy, including the health sector.

Our approach has three distinct features. First, following Lucas (1988), we concentrate on the ‘social planner solution’ of the model. In the absence of externalities, this solution coincides with the ‘market solution’ where agents are consuming, producing and accumulating in response to market prices. However, in this model several externalities are present which would be ignored in individual decision making.¹² We therefore, concentrate on the ‘social planner solution’.

The second feature of our approach is that we only analyse steady-state situations with balanced growth. That is, we show how the trade-offs mentioned above lead to a situation in the long run in which growth and health depend on the fundamental parameters reflecting technology and taste. The emphasis on differences in steady-state situations is in line with a quite impressive history of comparative growth studies that taught us that conditional convergence — in which different steady-state situations can occur — is much more plausible than absolute convergence.¹³ The transition to the steady-state situation is not part of our analysis. This is analytically impossible without resorting to numerical methods, whereas the insights gained from such an exercise will contribute very little to our present analysis of the consequences of the trade-offs.¹⁴

Finally, and in line with the second feature, we assume that in the steady-state both the average health and the age of population are constant. However, they are generated by the model and depend on the fundamental parameters that reflect technology and taste. We can then analyse how differences in technology or taste lead to differences not only in growth performance, but also in the health-state and age of population. As a consequence, exogenous productivity increases in the generation of health services, next to the endogenous efficiency increases in human capital accumulation, or an exogenous rise in the preference for health, can be used to explain long-term changes in the health-state and age of population. At this stage, however, we leave the endogenisation of the processes underlying these parameter changes for further research.¹⁵

The remainder of the paper is organised as follows. Section 2 introduces our model of population growth and longevity, while Section 3 describes the health generation process that we want to integrate with the Lucas (1988) model. Section 4 provides an overview of the extended Lucas (1988) model and presents the steady-state solution, while Section 5 shows how changes in the fundamental parameters of the model would affect the steady-state

¹² The generation of health services have an impact on productivity that would tend to be ignored in individual decision making.

¹³ For an overview, see for instance, Barro and Sala-i-Martin (1995).

¹⁴ In a much simpler model, Muysken et al. (1999) analyze the impact of health generation in an exogenous growth model. They use numerical methods to obtain the market solution. With respect to the dynamics of the model, their main finding is that, depending on the initial sizes of the stocks of physical capital and health, during the transition process optimal expenditures on health are lower or higher than in the steady-state.

¹⁵ An example is the explanation of the observation of Lapre and Rutten (1993, p. 32) that the value share of expenditures on health in national income rises with national income per head. This can be ‘explained’ by means of a positive relation between the preference for health and GDP.

solution. In Section 6 some (policy) implications of the model are discussed, while Section 7 provides a summary.

2. Longevity and population size

We introduce longevity in the model since this enables us to mimic the impact of ageing on growth and welfare by increasing the share of old people in the population. The population model we present here is designed in such a way that longevity can be introduced in the basic Lucas (1988) framework as simply as possible.

The population is subdivided into two parts: a part that is actively engaged in producing output, health services and human capital ('the young'), and a part that only consumes output and health services ('the old'). People live up to age T , but are actively involved in productive activities till age A . In order to simplify things even more, we assume that each year n persons are born that live for T years with health $g(t)$ and human capital $h(t)$, where t is a time index. At age T , people leave the population through sudden death. Consequently, the population is uniformly distributed over T year-classes with n persons in each year-class — and with identical health level $g(t)$ and human capital $h(t)$ per person over the whole population.

We now assume that the age A at which persons will retire from active participation in productive activities is fixed. Moreover, it seems reasonable to assume that longevity T is proportional to the average health level g of the population.¹⁶ We therefore have

$$T = \mu g \quad (1)$$

where μ is a constant factor of proportion.

From the above, it follows that the number of inactive people is equal to $(T - A)n$. A rise in longevity will therefore increase the number of inactive people in the economy, thus leading to a rise in the consumptive uses of the health sector, *ceteris paribus*. Consequently, the total population will increase with longevity. However, when the health level of the population stabilises, the number of births per period exactly matches the number of deaths, so that the population remains constant in the steady-state.

A good health may be also be expected to influence utility directly.¹⁷ In our case, this happens through the link between health, longevity and the size of the total population, using the following CIES (Constant Intertemporal Elasticity of Substitution) utility function:¹⁸

$$U = \int_0^\infty e^{-\rho\tau} \left(g^\gamma \left(\frac{C}{L} \right)^{1-\gamma} \right)^{1-\theta} \frac{L}{(1-\theta)} d\tau, \quad 0 < \theta < 1 \quad (2)$$

¹⁶ Since we concentrate on problems associated with an ageing population, we abstract from the impact of wealth or health on the birth rate. Therefore, the number of births per period does not depend on the health-state of the active population, nor on Malthusian economic circumstances.

¹⁷ This is noted by Grossman (1972, p. xiii), who says "... what consumers demand when they purchase medical services are not these services per se but rather 'good health'".

¹⁸ In the context of the CIES function, we ignore the possibility that $\theta = 1$, in which case we arrive at Eq. (2). Others have used a utility function like this too. See, for instance, Barro (1990, p. S117) and Barro and Sala-i-Martin (1995, p. 323) where government consumption services and leisure, respectively, take the place of health.

where ρ is the rate of discount, and $1/\theta$ is the intertemporal elasticity of substitution, $0 \leq \gamma \leq 1$ measures the relative contribution of health to intertemporal utility, compared to per capita consumption. Time $t = 0$ refers to the present, total private consumption is C , while $L = nT$ is the size of the population.

Since $(C/L)^{(1-\gamma)(1-\theta)} L = C^{(1-\gamma)(1-\theta)} L^{1-(1-\gamma)(1-\theta)}$, longevity T is an implicit argument (through L) of the utility function that contributes positively to utility (cf. Eq. (1)), next to the direct contribution of health in case $\gamma > 0$.¹⁹

3. The generation of health services

Because we want to integrate health and growth in an endogenous growth framework, we use a specification of the production characteristics of the health sector and its impact on health, that is as simple as possible. In order to integrate the notion of productivity increases due to human capital accumulation and decreasing returns, it is instructive to link up with some of the features of the Romer (1990) model. We describe our model of the generation of health services in dynamic terms. Since in the steady-state health will be constant, however, we will just use the implied steady-state relationship between health services inputs and health output as an implicit health production function. This paragraph provides the notions underlying that production function.

As mentioned above, we assume that the labour force consists of active people, and measured in physical units, it is constant. We assume furthermore that the amount of effective labour services that a person can supply is directly proportional to his average health level and human capital. Therefore, the supply of labour measured in efficiency units equals $hgnA$.

In the medical profession, there are two kinds of productivity gains: those from specialisation and those associated with individual specialisations becoming more productive due to increased knowledge within the field, or improved medical practices. Let us assume that the number of relevant specialisations Ω grows with the same rate as the human capital index, i.e. $\Omega = \pi h$. Knowledge within the field is assumed to grow with the rate of growth of human capital per person. However, the provision of health services takes place under conditions of decreasing returns — see, for instance, Forster (1989), Ehrlich and Chuma (1990), and Johansson and Lofgren (1995). Hence, the average health level of the population rises less than proportionally with the amount of health services rendered per person.

Let a fraction v_i of effective labour services be used as the sole input into the health generation process for specialisation i . Then $v_i hgnA/(nT)$ will measure the number of healthy hours spent on providing health services for specialisation i per person. Then, following the specialisation argument put forward in Romer (1990), the gross increase in the average health level of the population is given by²⁰

¹⁹ Because $0 < \theta < 1$ and $0 \leq \gamma \leq 1$, it follows that $1 - (1 - \gamma)(1 - \theta) \geq 0$.

²⁰ Note that this specification assumes that the demand for health services is the same for all age-classes, which is generally not true in practice. However, as long as the distribution of the population across age-classes is relatively stable, the mechanism described here also applies to a population that is heterogeneous (by age-class) in terms of its demand for health services. In order to simplify matters, we stick to Eqs. (3) and (4), however.

$$\frac{dg}{dt} = \int_0^{\pi h} \psi \left(h g v_i \frac{nA}{nT} \right)^\beta di = \psi \pi h \left(\frac{h g v A}{\pi h \mu g} \right)^\beta = \psi \left(\frac{A}{\mu} \right)^\beta \pi^{1-\beta} v^\beta h \quad (3)$$

where ψ is a productivity parameter and v represents the share of total effective labour supply employed in the health sector. The condition $0 < \beta \leq 1$ reflects the assumption of decreasing returns in health generation.

Technological change does not only have positive effects on health, though. It is quite conceivable that increases in the technological content of an average workers' job has led to higher incidences of burn-out due to stress, etc. Moreover, demand for medical care, i.e. the perception of health deterioration, will increase with the average level of medical technology in a society.²¹ We take this into account by assuming that the percentage loss of labour time due to these technology related factors is proportional to the level of technology πh with factor of proportion ς . The net increase in the average health level is now given by

$$\frac{dg}{dt} = \left[\psi \left(\frac{A}{\mu} \right)^\beta \pi^{1-\beta} v^\beta - \varsigma \pi g \right] h \quad (4)$$

An interesting feature of the health generation process is that it is inherently stable in the long run. It can easily be observed that for any given positive value of the share of the health sector in total employment v , the health level g will converge to g^* . The latter can be obtained by setting $dg/dt = 0$ in Eq. (3), which yields

$$g^* = \frac{\psi}{\varsigma} \left(\frac{A}{\mu} \right)^\beta v^\beta = z_0 v^\beta \quad (5)$$

where z_0 is implicitly defined by the equivalence of the right most part of Eq. (5) and its middle part. As one might expect, a higher share of employment in the health sector will result in a higher equilibrium health level g^* , while human capital formation as such increases the speed of adjustment towards that equilibrium level.

4. Health and the Lucas model

As we mentioned earlier, health enters the intertemporal decision framework in three different ways. *First*, a fall in the average health level of the population may be expected to cause a fall of the amount of effective labour services that the population can supply.²² *Second*, the generation of health takes scarce resources that have alternative uses (like the production of output or human capital), while *third*, a good health may be expected to influence utility directly. As we have discussed above, the latter includes the link between health, longevity and the size of the total population.

²¹ This argument is also used in Fuchs (1982).

²² Grossman (1972, p. xiii) states: "... the level of ill-health measured by the rates of mortality and morbidity, influences the amount and productivity of labour supplied to an economy".

Using the description of the health sector as given in the previous sections, the Lucas (1988) framework can be extended in a straightforward manner. The production structure is represented by

$$Y = B [(1 - u - v)hgnA]^\alpha K^{1-\alpha} \quad (6)$$

where Y measures total output, K the capital stock and B is a constant productivity parameter. Note that a fraction $(1 - u - v)$ of the supply of labour in terms of efficiency units is used in final output production, and the remaining fractions u and v are spent on human capital accumulation and health services production, respectively.

The human capital accumulation process has the same properties as in Lucas (1988) — the only difference is that we take health explicitly into account. Hence

$$\frac{dh}{dt} = \delta ugh \quad (7)$$

where δ is a productivity parameter. Finally, the accumulation of physical capital is given by

$$\frac{dK}{dt} = Y - C \quad (8)$$

As we explained in the introduction, we follow Lucas and concentrate on the so-called ‘social planner solution’. To solve the model, intertemporal utility (2) should be maximised with respect to C , the allocation of consumption over time, and u and v , the allocation of labour over its different uses, subject to the conditions (6), (7), (8) and (4).²³ Using the method of optimal control, it turned out to be impossible to find a closed form solution to the optimisation problem. In order to simplify matters therefore, we use the insight presented above that, for a constant steady-state allocation of effective labour services as we find in Lucas (1988), the health generation process is inherently stable in the long run. This implies that the health level will always converge to g^* defined in Eq. (5). We therefore replace the constraint of Eq. (4) by that of $g = g^*$ defined in Eq. (5). This is consistent with the focus of our analysis on long-term developments and balanced growth situations. Consequently, the out of steady-state behaviour of the health-state of the population will not be analysed, as stated in the introduction. And although the revised system still doesn’t allow us to obtain a closed form solution, we can rearrange it in such a way that we can employ a graphical solution method instead.

The first order conditions that the steady-state growth solution of the revised model has to obey can now be condensed into the following simultaneous equation system:²⁴

$$f = c^2 - \alpha c \quad (9.A)$$

$$v = \frac{f + \alpha(1 - \alpha)(1 - \theta)(1 - \gamma)/(\theta + (1 - \theta)2\gamma)}{f + ((1 + \beta)/\beta)\alpha(1 - \alpha)(1 - \theta)(1 - \gamma)/(\theta + (1 - \theta)2\gamma)} \quad (9.B)$$

²³ We simplify the original Lucas model somewhat by dropping the knowledge spill-over effect, which is not an essential ingredient of endogenous growth. The original Lucas model (without the knowledge externality) can be obtained by dropping (4) and setting $v = 0$, $g = 1$ and $A = L$ in (6) and (7).

²⁴ See the Technical Annex for more details.

$$c = 1 - \frac{(1 - \alpha)r}{(\theta + \gamma(1 - \theta))r + \rho} \quad (9.C)$$

$$r = \frac{\delta(1 - v)z_0v^\beta - \rho}{\theta + \gamma(1 - \theta)} = \frac{\delta g^*(1 - v) - \rho}{\theta + \gamma(1 - \theta)} \quad (9.D)$$

$$u = \frac{1 - c}{1 - \alpha}(1 - v) \quad (9.E)$$

where c is the average propensity to consume and r is the balanced growth rate of the system.

It should be noted that Eq. (9.D) is completely comparable to Lucas' growth results, i.e. $r = (\delta - \rho)/\theta$, for $g = 1$, $v = 0$ and $\gamma = 0$. From Eq. (9.D) it follows that the rate of growth rises with the productivity of both health generation and the human capital accumulation process. It also rises with the value of the intertemporal elasticity of substitution, which indicates the willingness of people to wait for their 'consumption' returns on investment (i.e. postponing current consumption until later). Likewise, a rise in the rate of discount indicates a decline in the valuation of future consumption possibilities, and hence reduces the rate of growth of the system.

Finally, Eq. (9.E) implies that in order to ensure $1 - u - v \geq 0$, we need $\alpha \leq c$. The steady-state savings rate therefore needs to be smaller than $1 - \alpha$. This is similar to the result found by Lucas for $v = 0$.²⁵

4.1. A graphical solution

Eqs. (9.A)–(9.D) need to be solved simultaneously, and u would then follow immediately from (9.E) and the simultaneous solution to (9.A)–(9.D). Unfortunately, that cannot be done in an analytical way. We use a graphical analysis instead. The analysis is based on the observation that Eqs. (9.A)–(9.C) define a relation between r and v , just like Eq. (9.D) does. Combining these two relations in the r, v -plane, and seeing how changes in the system parameters then shift these relations about in that plane, will give us information how the steady-state growth solution depends on those parameters.

In Fig. 1, we present a four-quadrant diagram to derive the relationship between r and v that follows from Eqs. (9.A)–(9.C). Eq. (9.A) is presented in the first quadrant as a relation between f and c , where we concentrate on the range $\alpha \leq c \leq 1$. It increases from $f = 0$ at $c = \alpha$ to $f = 1 - \alpha$ at $c = 1$. Similarly, Eq. (9.C) is represented in the fourth quadrant as a relationship between r and c , which decreases from $r = \rho/(1 - \gamma)(1 - \theta)$ at $c = \alpha$ to $r = 0$ at $c = 1$. Finally, in the second quadrant Eq. (9.B) is represented as a relationship between f and v . It increases from $v = \beta/(1 + \beta)$ for $f = 0$ to $v = v'$ at $f = 1 - \alpha$, while for f goes to infinity, v would asymptotically approach a value of 1.²⁶ The relevant range for v is therefore $\beta/(1 + \beta) \leq v \leq v'$, while the relevant range for r is given by $0 \leq r \leq \rho/(1 - \gamma)(1 - \theta)$. Any point within the latter range corresponds with a unique point in the former range by 'going round' in Fig. 1 in a counter-clockwise direction — mapping r onto c , c onto f and then f onto v . The resulting curve $v'r'$ in the third quadrant of

²⁵ Cf. Lucas (1988), p. 10.

²⁶ Here $v' = \{\theta + (1 - \theta)(\alpha(1 - \gamma) + 2\gamma)\}/\{\theta + (1 - \theta)(\alpha(1 - \gamma)((1 + \beta)/\beta) + 2\gamma)\} \leq 1$.

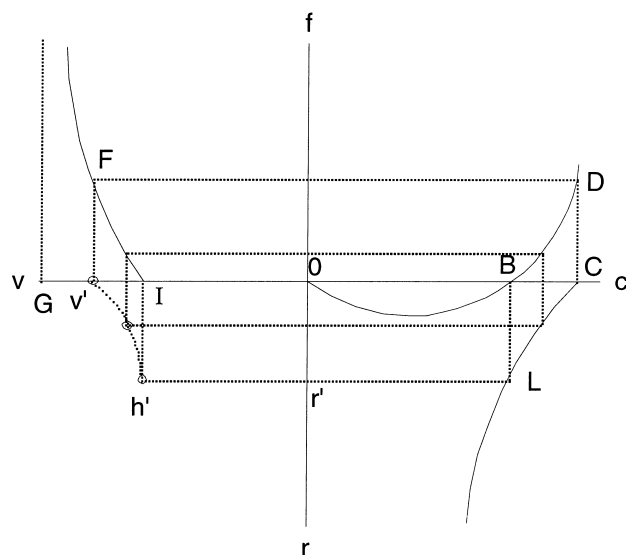


Fig. 1. A four quadrant diagram.

Fig. 1 summarises Eqs. (9.A)–(9.C). This curve can now be confronted with (9.D) to obtain the simultaneous solution of (9.A)–(9.D).

Eq. (9.D) describes r as a function of v . It is represented in Fig. 2, which corresponds to the south-west quadrant of Fig. 1. The curve has the same orientation as in Fig. 1. Eq. (9.D) is concave — it decreases from its maximum at r^* for $v = \beta/(1 + \beta)$ to $r = 0$ at $v^* < 1$.²⁷ The solution of the model is obtained at the point of intersection E of Eq. (9.D) and the curve $v'h'$. A unique solution exists if the curve $v'h'$ is convex and if $r^* < \rho/(1 - \gamma)(1 - \theta)$, $v^* > v'$.²⁸ We conclude that in the steady-state Y , C , K and h will grow at the equilibrium rate r_E , while health and longevity are constant at g_E^* and T_E , respectively. The latter are found by substituting v_E into Eqs. (5) and (1), respectively.

4.2. The trade-offs in the model

The trade-offs mentioned in the introduction that follow from the incorporation of health in the analysis, are now clearly reflected in the results we have obtained so far. The trade-off between health and human capital accumulation can be seen in Eq. (9.D). As we mentioned above, this equation is comparable to Lucas' growth results, i.e. $r = (\delta - \rho)/\theta$, for $g = 1$, $v = 0$ and $\gamma = 0$. The presence of the term $(1 - v)$ in Eq. (9.D) reflects the fact that a fraction

²⁷ The way in which r^* and v^* depend on the parameters of the model can be summarized by $r^* = r[\delta(+), z_0(+), \beta(+), \rho(-), \theta(-), \gamma(-)]$ and $v^* = v[\delta(+), z_0(+), \beta(+), \rho(-), \gamma(+)]$, where the sign within brackets denotes the sign of the partial derivative with respect to the parameter in question. These results follow directly from Eq. (9.D) and the requirement that $r(v^*) = 0$.

²⁸ In van Zon and Muysken (1997) we show that for plausible values of the parameters of the model, these constraints are likely to be satisfied. We assume this to be the case in the remainder of the analysis.

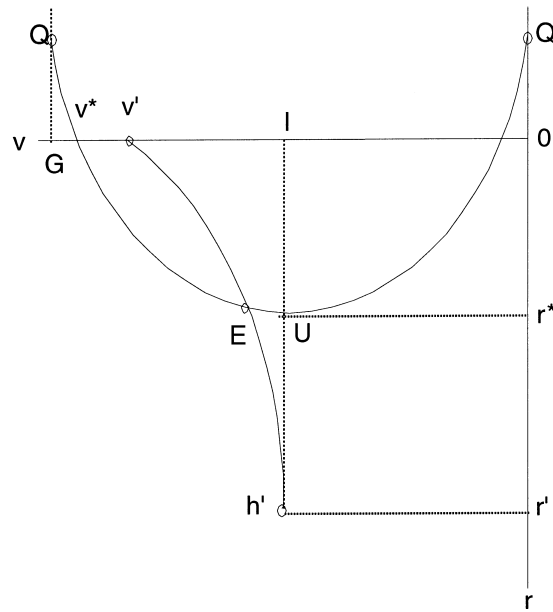


Fig. 2. The south-west quadrant again.

$(1 - v)$ of the labour force is not available for the generation of output or human capital, since its task is to maintain the average health level of the population at its steady-state value g^* . This lowers the maximum rate of growth attainable in the extended model as compared to the original Lucas model. The trade-off between consumption and health follows from the observation that, as is shown in the Technical Annex, disregarding the contribution of health to welfare by setting $\gamma = 0$ and treating the impact on longevity as a pure externality, leads to a growth maximising choice of v , i.e. $v = \beta/(1 + \beta)$. But if we do take account of the direct welfare effects of health generation also through its impact on longevity, Fig. 2 shows that the point of intersection between the two curves implies a value of r that is lower than r^* , while in that case $v > \beta/(1 + \beta)$. Hence, the incorporation of the direct contribution of health to welfare (also through longevity) increases the level of health services at the expense of growth (but not of welfare), *ceteris paribus*.

5. A comparison of steady-states

As we mentioned in Section 1, we want to analyse how the steady-state characteristics of the model depend on the fundamental parameters that represent technology and taste. The relevant technology parameters are δ and z_0 , i.e. the productivity of human capital accumulation and health generation, respectively, while the relevant taste parameters are $1/\theta$ and ρ , reflecting the intertemporal elasticity of substitution and the discount rate, respectively.

In order to illustrate what happens to health, growth and to the size of the health-sector for various constellations of the parameters of our model, we have used a graphical analysis

Table 1
Parameter changes and health and growth responses

Parameter	$c = 1 - s$	v	u	r	g^*
θ	+	+	–	–	+
ρ	+	+	–	–	+
δ	–	–	+	+	–
z_0	–	–	+	+	?(+)
γ	+	+	–	–	+

based on Fig. 2.²⁹ We summarise the results in Table 1, in which positive and negative influences of a positive change in a parameter are indicated by a + sign and a – sign, respectively. Ambiguous reactions are indicated by a question mark followed by a sign within brackets, which indicates the sign we would expect.

The first thing to notice from this table is the negative correlation between the effects of a parameter change on growth and on the propensity to consume. This is due to the fact that there is a positive correlation between the saving rate s and the rate of growth itself. The reason is that for a stable value of the capital output ratio, a rise in the saving rate is required in order to sustain a higher rate of growth. Secondly, v and u are negatively correlated, instead of positively as suggested by micro economic analysis.³⁰ In our model, the negative correlation exists because both health production and human capital accumulation compete for the same scarce labour resources, for a fixed size of the active labour force measured in physical units. Thirdly, there is in most cases a negative correlation between the level of health and the rate of growth. This follows from the positive impact of increased health on longevity, which in its turn increases the demand for health care, at the expense of growth.

Let us now turn to the interpretation of the individual results. A rise in θ implies a fall in the value of the intertemporal elasticity of substitution. This means that people become more reluctant to wait for their return on investment, and consequently they are inclined to increase current consumption of goods, but also of health services. This is reflected in a rise in the steady-state values of c , v and g^* , accompanied by a fall in r itself, but also in u . Note that a rise in θ also implies an increase in the relative contribution of longevity to welfare, as we discussed in Section 2.

The results for a rise in θ are very similar to those obtained for a rise in the rate of discount ρ .³¹ This is to be expected since a rise in ρ reflects the decrease in the subjective valuation of the utility derived from the consumption of a certain package of goods and health-services in the future relative to the valuation of the utility of that same package when it would be consumed today. Hence, one would expect people to spend more resources on fulfilling

²⁹ Basically, the analysis consists of calculating the shifts of the two relations between v and r in Fig. 2 due to a change in one of the parameters, in order to see how the new equilibrium would be affected. These shifts can be calculated directly by differentiating $r = r(v)$ as given by (9.D) with respect to the various parameters, or by differentiating the 'chain' of relations $c = c(r)$, $f = f(c)$, and $v = v(f)$ as given by (9.A)–(9.C) with respect to those parameters to obtain the shift in v for a given value of r . For the full technical details, see Annex F of van Zon and Muysken (1997).

³⁰ Cf. Fuchs (1982), for instance, as is elaborated in Footnote 5.

³¹ There are differences though, as explained in more detail in Annex F of van Zon and Muysken (1997).

current needs, by redirecting labour input to activities that increase present consumption possibilities, rather than future ones. Consequently, c , v and g^* rise, while r and u fall.

A rise in the productivity of human capital accumulation, i.e. δ , has quite different effects. Since the latter increases the marginal benefits of investing in human capital accumulation, a reallocation takes place of labour from activities that increase current utility to activities that increase future utility. Consequently, growth is positively affected. In order to make this possible, c and v fall, while u and r increase. Also g^* falls because of the reduction in v .

The previous results are very similar to those obtained for an increase in the productivity of the health sector, i.e. ψ , which corresponds to an increase in z_0 (see Eq. (5)). This corroborates the ‘engine-like’ features of the health sector that we pointed out in Section 1. Because an increase in ψ would tend to increase g^* for a given v , it would also permanently increase the productivity of the human capital accumulation process. The productivity increase in the health sector then enables a contraction of the allocation of labour resources to that sector (v falls). The net effect on g^* is therefore ambiguous, but one would expect g^* to rise,³² which in turn makes investment in human capital accumulation more profitable because of its intertemporal spill-over effects. Hence u rises, and so does r . Similar results are readily obtained for the other structural parameters that define z_0 . We do not repeat them here.

A rise in the direct impact of health on utility γ has all the expected effects. It reduces growth and raises average health by changing the allocation of human capital in the direction of health production. In addition to this, the average propensity to consume can rise, because of the slow down in growth.

Finally, it is worth mentioning that the effective productivity of the health sector may be that low (either due to a high value of ζ or low values of β , ψ or A/μ), that the curve given by Eq. (9.D) describes just a few instances of v that generate (moderately) positive growth.³³ Such parameter constellations may be relevant for the poorer developing countries, for example. In that case, aid aimed at changing the system parameters mentioned above, may well help growth to take off. Growth may even become self-sustaining if medical aid succeeds in raising life expectancy, and lowering the rate of discount which, by shifting Eq. (9.D), would lead to more promising growth potentials. It should be noted that for the richer countries too, a rise in γ would result in a reduction in growth performance. However, in the latter case that would be choice rather than fate.

6. Model implications

The model has a number of interesting implications. Before pointing these out, however, we would like to stress again that our analysis applies to long-term developments

³² In the decreasing returns setting we have defined, one would expect a reaction to an exogenous shock not to be able to wipe out all the effects of such a shock, because such a reaction would involve the re-allocation of resources which were initially allocated in such a way as to generate maximum overall benefits for a given stock of scarce irreproducible labour resources. In fact that is exactly what we found during exploratory simulations with our model using ‘reasonable’ parameter values, where we observed a fall in g^* despite the rise in v which is required to counter the effects of a rise in ζ . Note that a rise in ζ would have the same effect as a fall in ψ . See van Zon and Muysken (1997) for more details.

³³ This might also be caused by a high value of the rate of discount ρ or a high value of the relative contribution of health to welfare γ .

and balanced growth situations. The phenomena we discuss here — like the productivity slow-down — could be interpreted to occur in the transition to a steady-state growth situation, in which case they would have to be explained from the transitional dynamics of the growth model. However, they could also be explained as the outcome of a process of balanced growth, where different situations correspond to different parameter constellations regarding technologies and tastes. We present the latter explanation in this analysis.

First of all, the fact that we have a decreasing returns health sector which level of activity defines the effective availability of human capital within the economy, makes the efficiency of this sector one of the central determinants of economic performance. Indeed, the notion that effective inputs of human capital and labour into the various production processes depend on one's health status, makes health a complement to growth from a supply perspective. Moreover, a change in ψ or ς (and to a lesser extent A and μ depending on the value of β (cf. Eq. (5)) is as important for growth as an equal proportional change in δ . This stresses the importance of health as a determinant of both the level and the growth of labour productivity, quite apart from the direct positive welfare effects induced by changes in the productivity of the health sector.

Second, the influence of the decreasing returns nature of the health sector on growth provides an interesting alternative explanation for the productivity slow-down. If, as seems reasonable to assume, the preference of people for a good health rises with the standard of living, i.e. γ rises with output per head, then growth would automatically slow down in the process.

Third, the average age of the population in Western European economies has shown a tendency to rise during the last decades. This introduces a wedge between the two functions of the population in our model. It is the active population that determines labour supply, and hence the scale of all economic activities which rely on the use of labour services, while the total population determines the scale of the demand for health-services. Hence, technological breakthroughs in medicine could be expected not only to boost overall productivity, but also to provide a brake on productivity growth, although not necessarily on the growth of welfare, through rises in longevity.

Fourth, in the case of high values of the rate of decay of health, due to malnutrition for instance, people may have such a high preference for consumption now, reflected by a low value of the intertemporal elasticity of substitution (i.e. a high value of θ), that they could become stuck in a 'no growth', 'low health' situation because there are only very few, if any, instances of v with positive growth. This suggests that policies aimed at furthering growth by means of reducing ζ , or increasing δ_H , through direct aid in the form of technology or income transfer, may induce growth which is sufficiently high to lower the rate of discount ρ and increase the intertemporal elasticity of substitution $1/\theta$ to such an extent, that savings will arise that will allow growth to take-off and become self-sustaining.

7. Summary and conclusion

In this paper, we have presented a simple model of endogenous growth based on the Lucas (1988) model, in which a good health functions as a necessary condition for people to be able to provide labour services. At the same time, health is produced under conditions

of decreasing returns, whereas human capital is produced under conditions of increasing returns. If we regard the impact of health on longevity as an externality, we find that the health sector has a size that is consistent with maximum economic growth. In that case, health is a pure complement to growth, and any re-allocation of labour from the health sector towards human capital accumulation activities would cause a decline in growth.

In our model, however, we internalise the impact of health on longevity, because part of total welfare at the population level comes in the form of longevity itself. In order to solve the resulting steady-state values of growth and health, we devised a graphical procedure that enables us to show that increases in the demand for health services caused by an ageing population, will now adversely affect growth; next to being complements, as mentioned above, health and growth have also become substitutes. This provides a dynamic version of Baumol's disease with respect to the health sector — in particular when the preference of people for a good health rises with the standard of living.

We also concluded that, since the steady-state growth rate rises linearly in the average health-level of the population, the productivity of the health-sector is as important a determinant of growth as the productivity of the human capital accumulation process itself.

Finally, we have arrived at the conclusion that there may be circumstances regarding the provision of health-services and life expectancy, in which it may be hard for growth to take place at all. Aid meant to improve the productivity of the health-sector or the net availability of human capital resources for non-health activities in the poorer developing countries, could actually lead to growth taking off on its own. Growth can even become self-sustaining if the rate of discount would fall and the intertemporal elasticity of substitution would rise in the face of structural gains in life expectancy.

Appendix A. Technical annex

The Hamiltonian of the revised system can be written as

$$H = e^{-\rho t} C^{\gamma_1} (n\mu)^{\gamma_2} (g^*)^{\gamma_3} / (1 - \theta) + \lambda (B((1 - u - v)g^* h n A)^{\alpha} K^{1-\alpha} - C) + \xi \delta u g^* h \quad (\text{A.1})$$

where C , u and v are the control variables, and K and h are the state variables that grow with the balanced growth rate in equilibrium. $g^* = z_0 v^{\beta}$ is a 'quasi'-state variable, since it must be constant in the steady-state. Moreover, $\gamma_1 = (1 - \gamma)(1 - \theta)$, $\gamma_2 = 1 - \gamma_1$ and $\gamma_3 = 1 - (1 - 2\gamma)(1 - \theta)$. Note that for a value of $\gamma \geq 1/2$ we have $\gamma_3 \geq 1$.

The first order conditions with respect to the control variables are

$$\frac{\partial H}{\partial C} = (1 - \gamma) e^{-\rho t} C^{\gamma_1 - 1} (n\mu)^{\gamma_2} (g^*)^{\gamma_3} - \lambda = 0 \quad (\text{A.2})$$

$$\frac{\partial H}{\partial u} = -\frac{\lambda \alpha Y}{(1 - u - v)} + \xi \delta g^* h = 0 \quad (\text{A.3})$$

$$\frac{\partial H}{\partial v} = \frac{\gamma_3 \beta e^{-\rho t} C^{\gamma_1} (n\mu)^{\gamma_2} (g^*)^{\gamma_3}}{(1 - \theta) v} - \frac{\lambda \alpha Y}{1 - u - v} + \frac{\lambda \alpha Y \beta}{v} + \frac{\xi \delta u \beta g^* h}{v} = 0 \quad (\text{A.4a})$$

If we would ignore the direct influence of health on welfare as well as the influence through longevity, i.e. treat L as given in the welfare function and not substituting (1) in the welfare function while setting $\gamma = 0$, Eq. (A.4a) is reduced to

$$\frac{\partial H}{\partial v} = -\frac{\lambda\alpha Y}{1-u-v} + \frac{\lambda\alpha Y\beta}{v} + \frac{\xi\delta u\beta g^*h}{v} = 0 \quad (\text{A.4b})$$

Substituting (A.3) into (A.4b) and then solving for v , gives us $v = \beta/(1+\beta)$. But if we do take account of (1) and substitute $C = (1-s)Y$, where s is the saving rate, as well as (A.2) and (A.3) into (A.4a), we get

$$\frac{(1-s)\gamma_3\beta}{(1-\gamma)(1-\theta)v} - \frac{\alpha}{1-u-v} + \frac{\alpha\beta}{v} + \frac{\alpha u\beta}{(1-u-v)v} = 0 \quad (\text{A.5})$$

Substitution of (A.3) in the first order condition $\partial H/\partial h = -d\xi/dt$ leads to the following result

$$-\hat{\xi} = \delta g^*(1-v) \quad (\text{A.6})$$

Assuming the existence of a steady-state, we can use (A.6), (A.2) and the underlying production function in order to obtain

$$r = \hat{Y} = \hat{K} = \hat{h} = \hat{C} = -\frac{(\hat{\xi} + \rho)}{\theta + \gamma(1-\theta)} = \left(\frac{\delta g^*(1-v) - \rho}{\theta + \gamma(1-\theta)} \right) \quad (\text{A.7})$$

which is the same as Eq. (9.D). The rate of growth of human capital accumulation is given by

$$\hat{h} = \delta u g^* \quad (\text{A.8})$$

Moreover, from the condition that $\partial H/\partial h = -d\lambda/dt$ and (A.2) in combination with the definition, $s = (dK/dt)/Y = \hat{K}/(K/Y)$ and $\hat{C} = \hat{K}$, it follows directly that

$$s = (1-c) = \frac{(1-\alpha)r}{(r(\theta + \gamma(1-\theta)))} + \rho \quad (\text{A.9})$$

which is equivalent to Eq. (9.C). Substituting (A.8) into the numerator of (A.9) and (A.7) into the denominator of (A.9), we have

$$(1-c) = \frac{(1-\alpha)u}{(1-v)} \Rightarrow u = \frac{(1-c)(1-v)}{(1-\alpha)} \quad (\text{A.10})$$

(A.10) is the same as Eq. (9.E). Substitution of $c = 1-s$ and (A.10) into (A.5) and solving for v , results in

$$v = \frac{c(c-\alpha) + \alpha(1-\alpha)(1-\theta)(1-\gamma)/(\theta + (1-\theta)2\gamma)}{c(c-\alpha) + ((1+\beta)/\beta)\alpha(1-\alpha)(1-\theta)(1-\gamma)/(\theta + (1-\theta)2\gamma)} \quad (\text{A.11})$$

which is the same as Eq. (9.B) after substituting $f = c(c-\alpha)$. The latter relation between f and c is the same as Eq. (9.A).

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